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A Study on the Safety Regulatory Framework Analysis and Graded Regulation for Zero Power Research Reactors in South Korea

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1. Introduction

For rational regulation of nuclear reactors, various attempts have been continuously suggested to apply graded licensing procedures, regulatory requirements, and regulatory activities according to the unique characteristics of the facilities [1]. In particular, in recent years, various efforts have been made to apply graded regulations internationally to introduce SMR (Small Modular Reactor).

Currently, the Korean government is focusing on securing core i-SMR technology and introducing the 'Korea-Advanced Reactor Demonstration Program(K-ARDP)' as a support measure to quickly secure technology and initiative in response to the global next-generation nuclear reactor market, which is expected to bloom in the early 2030s.

In general, when developing a new concept of nuclear power system, construction and experiments are carried out in the order of critical assembly, experimental reactor, prototype reactor, and demonstration plant to secure elemental technology. However, the reactor licensing system in South Korea is managed only in two categories; nuclear power reactors and research reactors. Research reactors have lower heat output compared to nuclear power reactors which are for power generation, for example, HANARO, 30 MWth, is only about 1/100 of the heat output of a 1,000 MWe nuclear power plant. In general, since the reactor's radioactive material inventory is proportional to its heat generation, it is not reasonable at all to regulate research reactors on the same basis as nuclear power reactors in terms of radioactive discharges and radiological impact on the environment. In particular, AGN-201K with 10 Wth, which is the only educational proposed zero power research reactor in the South Korea, has about 1/1,000,000 compared to HANARO, but is regulated as the same category under current domestic law.

Ultimately to secure technology from initial core design to final demonstration reactor construction, it is urgent to maintain flexible laws and regulations considering the construction and operation of zero power critical assemblies and low-power experimental reactors to secure SMR and next-generation reactor element technology.

Therefore, this study investigates and analyzes the regulatory status of domestic and international research reactors, and derives and proposes the necessity of introducing graded regulations in research reactors. In particular, research reactors aim not to produce heat energy through nuclear fission, but to utilize neutrons or radioactive substances as a by-product of nuclear fission reactions, so their thermal output and radiation levels are significantly lower than those for nuclear power reactors, so their physical properties are closer to Radiation Generating Device (RG). Therefore, by comparing and analyzing the safety regulation system of radiation generators together, we intend to derive a graded regulation plan applicable to zero power research reactors.

2. Domestic and International Trends and Nuclear Safety Regulation of Research Reactors

The current status of regulatory frameworks for both domestic and international research reactors were investigated in this chapter. Most countries, including South Korea, apply regulations to research reactors that are identical or similar to the licensing procedures for nuclear power reactors. However, the United States and Japan implement graded regulation for research reactors by establishing own regulatory examination guidelines distinct from nuclear power reactors [2].

2.1 Domestic Trends and Nuclear Safety Regulation of Research Reactors

South Korea classifies nuclear reactors into two main categories: nuclear power reactors and research reactors. However, some licensing procedures feature a graded approach based on thermal output. For instance, as seen in Table I, facilities with a thermal output of less than 100 kW are exempt from providing a quality assurance plan for the construction and operation permit, a survey of the radiation environment, and an environmental report [3].

Table I: Domestic Exemption of a Survey of the Radiation Environment, and an Environmental Report

Thermal Output Standard	Exemption
< 100 kW	a survey of the radiation environment, and an environmental report

A graded approach is also applied to the Radiation Emergency Planning Zone (EPZ) [4]. The EPZ is a designated area established to protect the public in the event of a radiological emergency or nuclear disaster, and it is typically divided into a Precautionary Action Zone (PAZ) and an Urgent Protective Action Planning Zone (UPZ). In the South Korea, a lessened regulatory is adopted for the establishment of EPZs, as seen in Table II, concerning research reactors and relevant facilities, compared to that for nuclear power reactors.

Table II: Domestic Radius of PAZ and UPZ Depending on Types of Reactors and Related Facilities

Facility		PAZ	UPZ
Power Reactor and Related Facilities		3 km≤ R ≤ 5 km	20 km ≤ R ≤ 30 km
Research Reactor and Related Facilities	2 MW ≤ P_{th}< 10 MW	None	R around 0.5 km
	10 MW ≤ P_{th} < 50 MW	None	R around 1.5 km
	50 MW ≤ P_{th} < 100 MW	None	R around 5 km
Nuclear Facilities Other than Above		None	Site Boundary

* R refers to the radius of each EPZ.
* P_{th} refers to the thermal power of each reactor.

Furthermore, starting from 2025, a licensing supplementary educational training program targeting research reactors with a thermal power of less than 10 MW is scheduled to be implemented [5]. Table III shows the comparison between the existing supplementary educational training programs with the new supplementary educational training program for reactor operator license in South Korea. In the new program, certain theoretical subjects exclusively relevant to nuclear power reactors have been excluded, and the curriculum has been structured to focus on issues potentially occurring in reactors with a thermal power of less than 10 MW.

Table III: Domestic Reactor Operator License Management System

Facility	Licensing Supplementary Educational Training Program
Standard Reactor, APR, Westinghouse, Framatome, CANDU, and Research Reactor ≥ 10 MW	3.5 hours theory lecture (1 day) + 1.5 days practical training, total 5 days
Research Reactor < 10 MW	1 day theory lecture + 0.5 day practical training

Additionally, practical training sessions have been also excluded due to reasons such as the absence of simulators. Therefore, this can be seen as a domestic case where a graded approach is applied in licensing and regulatory requirements. Even within the same category of research reactors, regulations were graded based on a thermal power of 10 MW.

2.2 United States of America's Trends and Nuclear Safety Regulation of Research Reactors

Reactors in the United States of America are mainly categorized into power reactors and non-power reactors. Non-power reactors are further subdivided into test facilities, research reactors, and commercial or industrial reactors [6]. In the United States of America, given the lower risk associated with non-power reactors, they are subject to graded regulations than power reactors. For example, the Nuclear Regulatory Commission (NRC) requires an Environmental Impact Statement (EIS) for power reactors during the permitting process, but not for research reactors. Even during normal operations, a graded approach applies to the technical safety standards and Accident Evaluation Criteria applicable to power reactors.

Graded regulations also exist between test facilities and research reactors. Under the National Environmental Protection Act of 1969 (NEPA), the permitting process for non-power reactors is divided into three categories: Categorical Exclusion (CatEx), Environmental Assessment (EA), and Environmental Information System (EIS). While test facilities require an EA or EIS, research reactors require an EA only for construction permits, initial operating licenses, license renewals, decommissioning planning orders, and license terminations. Specifically, the NRC requires the submission of a Generic EA for construction permits, initial operating licenses, and license renewals for research reactors and critical assemblies with operating licenses of 2 MW or less.

Site Suitability Criteria also shows differences between reactor types. For the dose limit of the individual members of the public assuming an accident, the 10CFR100 standard is applied to the test facility and the 10CFR20 standard is applied to the research reactor [2].

Emergency planning requirements are also graded according to the thermal power range. In the United States of America, emergency planning-related regulations are divided into four categories: 100 W or less, 100 W to 100 kW, 100 kW to 2 MW, and more than 2 MW [7].

i. Testing and research reactors under 100 W are exempt from The identification by title of the individual, who may authorize volunteer emergency workers to incur radiation exposures in excess of normal occupational limits.
ii. Testing and research reactors under 100 kW are exempt from The functions as applicable

to emergency planning of Federal, State, and local government agencies and the assistance that they would provide in the event of an emergency.

iii. Testing and research reactors under 2 MW are exempt from The capability of the emergency organization to function around-the-clock for a protracted period of time following the initiation of emergencies that have or could have radiological consequences requiring around-the-clock emergency response.

For EPZs, the United States of America applies various EPZ sizes across five distinct power categories for research reactors: less than or equal to 2 MW, 2 to 10 MW, 10 to 20 MW, 20 to 50 MW, and greater than 50 MW. Table IV shows the EPZ radii for each thermal power range.

Table IV: Radius of EPZ of Research Reactor Depending on Thermal Power in the United States of America

Facility	EPZ
$P_{th} \leq 2$ MW	Operations boundary
2 MW < $P_{th} \leq 10$ MW	R= 0.1 km
10 MW < $P_{th} \leq 20$ MW	R= 0.4 km
20 MW < $P_{th} \leq 50$ MW	R= 0.8 km
P_{th} > 50 MW	Case dependent

* R refers to the radius of each EPZ.
* P_{th} refers to the thermal power of each reactor.

2.3 Japan's Trends and Nuclear Safety Regulation of Research Reactors

Japan published a document called "New Regulation Standard and It Interpretation" on November 27, 2013, and defined the research reactors as "Research and Test Reactor" in General Provisions and laws. In this document, research and test reactors are divided into critical experimental facility, water-coupled research factor, gas-coupled factor, sodium-cooled factor, floating nuclear plant. As shown in Table V, they were also subdivided into low-level power, intermediate-level power, and high-level power reactor according to the thermal power of research and test reactors. In addition, the criteria for design are individually specified for each of the research and test reactors classified into five categories.

Table V: Classification of Research and Test Reactors by Thermal Power in Japan

Category	Thermal power
Low-level power reactor	P_{th} < 500 kW
Intermediate-level power reactor	500 kW ≤ P_{th} < 10 MW
High-level power reactor	10 MW ≤ P_{th} < 50 MW

* P_{th} refers to the thermal power of each reactor.

In addition, Japan also sets the size of the EPZ differently as shown in the following table, according to the factor power [6].

Table VI: Radius of EPZ of Research Reactor Depending on Thermal Power in Japan

Facility	EPZ
$P_{th} \leq$ 1kW	R= 50 m
1kW < $P_{th} \leq$ 100 kW	R= 100 m
100 kW < $P_{th} \leq$ 10 MW	R= 500 m
10 MW < $P_{th} \leq$ 50 MW	R= 1500 m
P_{th} > 50 MW	R= 8 ~ 10 km

* R refers to the radius of each EPZ.
* P_{th} refers to the thermal power of each reactor.

3. Suggestion for Zero Power Research Reactor Regulation – Grading and Categorical subdivision

This study aims to propose improvements, such as the introduction of new regulation grade (i.e., zero power research reactor and low-medium power research reactor), through a more segmented approach to research reactors. This approach is based on each reactor's operational purpose, design characteristics, performance, and current trends in domestic and international safety regulatory guidelines. To this end, a graded regulatory framework is proposed that classifies existing research reactor categories into 'zero power research reactors' and 'low-medium power research reactors' based on their thermal power levels. For low-medium power research reactors, the current research reactor regulatory system is applied mutatis mutandis. In contrast, zero power research reactors are designated as separate graded regulation, considering their inherent very-low thermal power characteristics.

3.1 New Regulation Grade for Zero Power Research Reactor

A graded regulation framework is thus proposed that classifies existing research reactor categories into 'zero power research reactors' and 'low-medium power research reactors' based on their thermal power levels. The International Atomic Energy Agency (IAEA) emphasizes power level as a one of the important elements in applying a graded approach to the licensing of research reactors [8].

Table VI presents the IAEA's three-group classification of research reactors for graded approach, categorized by thermal power [9]. Table VII shows various thermal power boundaries in domestic and international graded regulations for research reactors. Building on those boundaries, this study conservatively proposes 100 W as the demarcation between zero power and low-medium power research reactors.

Table VI: Three-Group Classification of Research Reactors from IAEA

Group	Thermal Power	Classification Criteria
Group I	0 ~ 0.5 MW	Normal leak tightness of building, reactor structures intact; no accident scenario requiring immediate action due to major damage or significant radiation release
Group II	0.5 ~ 2 MW	Normal leak tightness maintained; minor debris from internals; accident scenario requiring immediate action only if debris blocking or critical
Group III	2 ~ 5 MW	Leak tightness function may be degraded; some debris present; some additional functions guaranteed; immediate action accident scenario coverage

Table VII: Domestic and International Thermal Power Boundaries for Regulation Grading of Research Reactors

Case		Thermal Power Boundary	Criteria
International	IAEA Proposal Research Reactor Group	< 0.5 MW	Group I
	New Regulatory Standard for Research Reactor	< 500 kW	Low power reactor's standard in "New Regulatio n Standard"
Domestic	A survey of the radiation environment, and an environmental report	< 100 kW	Exempt
	Radiation Safety Plan	< 100 W	Exempt
	EPZ	< 2 MW	- No PZA - UPZ boundary
	Reactor Operator Licensing Supplementar y Educational Training Program	< 10 MW	Graded regulation on theoretical and theoretical education

3.2 Combined License Process for Zero Power Research Reactor

Unlike research reactors for complex equipment with high thermal power, zero power research reactors and critical assemblies are designed with simple structures. The integrated construction permit and operation license procedures can be expected to simplify and shorten the examination period. Therefore, for the zero power research reactor, a combined License (COL) Process is proposed. In this case, the submission documents require a safety analysis report, a quality assurance plan for construction and operation, technical specifications for operation, and a decommissioning plan, excluding the radiation environment investigation according to existing exemption matters .

3.3 Exemption of PSR for Zero Power Research Reactor

With an amendment of The Nuclear Safety Act in 2014, the Periodic Safety Review (PSR) system started to be applied to research or educational factors. However, the reviews have not been completed until now in 2025, even though the first report of HANARO and AGN-201K was submitted to the regulatory body in 2018. This strongly suggests the need to improve the effectiveness and efficiency of safety regulations. In particular, AGN-201K, an educational zero power factor, did not require or partially evaluate 7 out of a total of 14 items in the first PSR. Accordingly, PSR exemption is proposed for zero power factors for the following three reasons.

i. Zero power research reactors do not have Engineered Safety Features or active safety-related equipment.
ii. The Structures, Systems and Components (SSC) of the zero power research reactor have a very low possibility of aging due to operation.
iii. Among the 14 PSR items, only a limited number can effectively evaluate the maintenance of safety functions, and even when necessary, alternative evaluations can be conducted using existing means such as Regular Inspections.

4. Conclusion

In general, research reactors have various characteristics depending on their type and purpose of use, but in the current regulatory system, laws on the nuclear power reactors are applied mutatis mutandis to most matters. The limited regulatory resources may be wasted in the process of conservatively applying the power generation reactor without considering unique characteristics of research reactors. Therefore, this study compared and analyzed the safety regulatory system of domestic and international research reactors and suggested the necessity of introducing a graded approach for zero power research reactors. This study proposed a new regulatory grade system that divides the heat output 100 W into 'zero power research reactors' and ' low-medium power research reactors' as the boundary, and suggested regulatory rationalization for zero power research reactors, such as combined license procedures, exemption from PSR, and relaxation of the obligation to submit some documents. This will enable the efficient allocation of regulatory resources and shorten the licensing period and can serve as a basis for improving the research and development environment for SMR and Gen-IV reactors and securing core source technologies.

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